Ecology and seasonal distribution of two genera of diatoms, *Cocconeis* and *Licmophora*, recorded in the Nador Lagoon (North-East Morocco)

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Abstract. The main purpose of this research was to evaluate the seasonal and temporal variations of physico-chemical parameters and to determine the main species of two genera of phytoplankton *Licmophora* and *Cocconeis* in the Lagoon of Nador, according to two seasons, spring and summer. During the sampling, and during the rainy season (spring), *Cocconeis* was dominant with a density of 5840 cells L^{-1}, and the most dominant species was *Cocconeis scutellum* Ehrenberg 1838. During the dry season (summer), *Licmophora* was dominant with a density of 840 cells L^{-1}, and the most dominant species was *Licmophora gracilis* (Ehrenberg) Grunow, 1867. The species distribution of the phytoplankton community was caused by seasonal and temporal variation conditions.

Key Words: *Cocconeis scutellum*, *Licmophora gracilis*, Nador Lagoon, physico-chemical parameters.

Introduction. Diatoms are microscopic single-celled plants that live in fresh, brackish and marine waters from the poles to the tropics (Trainer et al 2008). They play an indispensable role in the aquatic food web, contributing to 40% of ocean primary productivity and 20% of global carbon fixation (Hildebrand 2008); they are also important in the assessment of ecological status (Stevenson et al 1999).

Diatoms belonging to the class Diatomophyceae (Bacillariophyceae) constitute an extremely diverse group. Mann (1999) reports that this class is highly diverse, with an estimated number of species between 0.1 and 1 million. Diatomophyceae have been previously studied in the Mediterranean (Caroppo et al 2006; Sahraoui et al 2009; Solak et al 2018). Diatoms are the most successful group of photosynthetic eukaryotes. Their high photosynthetic activity and their tendency to dominate phytoplankton communities have led to their major involvement in primary production. It has been estimated that diatoms contribute to 40-45% of ocean primary productivity, accounting for 20% of global carbon sequestration and oxygen production (Yool & Tyrrell 2003). Diatoms are microalgae considered most sensitive to environmental conditions such as organic pollution and eutrophication (Drira et al 2009). Some diatom species are directly or indirectly responsible for human health problems (Lefebvre & Robertson 2010).

Human activities cause an increase in nutrients that trigger eutrophication marked by the proliferation of phytoplankton (Piranti et al 2021). Nutrients are a support factor that phytoplankton needs to develop, especially nitrates and phosphate (Zahro et al 2021).

However, the group of benthic diatoms, which are part of the phytoplankton, is one of the most visible, abundant (Hernández Almeida & Siqueiros Beltrones 2008) and productive of the marine microphytobenthos. Benthic diatoms also play an important role in the biogeomorphological dynamics of the seabed by producing extracellular polymers that stabilize sediments (Blanchard et al 2000; De Brouwer & Stal 2002; Stal 2010), thus preventing the erosion of coastal lagoons and estuaries. On the other hand, benthic diatoms are the main food for a large number of organisms; their contribution to the diet of suspension feeders and grazers has recently been shown to be greater than that of seagrasses (Lebreton et al 2011).

The contribution of benthic diatoms to water column biomass (via resuspension) can be up to six orders of magnitude greater than that of phytoplankton (De Jorge & Van Beusekom 1995), while chlorophyll-a in the microphytobenthos (mainly diatoms) can account for 50% to 60% of the total (Van Beusekom & Jonge 1992). Finally, this characteristic of diatoms also plays an important role in biogeochemical cycles, as they form complex biofilms that are suitable substrates for different types of organisms and interactions in which consumption and remineralization of nitrogen, phosphorus and oxygen take place (Sundbäck & Graneli 1988; Sundbäck & Jönsson 1988; Hochard et al 2010).

Worldwide, the study of marine benthic diatoms has been limited, mainly due to inherent difficulties in species identification. The main objective of this study is to present the diatoms in particular the genera *Licmophora* and *Cocconeis* and their distribution in the Lagoon of Nador, by providing their descriptions based on observations in inverted optical microscopy.

Material and Method

Study area and location of stations. Morocco is a coastal country with 3400 km of coastline (Mediterranean Sea on one side and the Atlantic Ocean on the other). Nador Lagoon is on the Mediterranean coastline, being one of the most important lagoons at national and regional level by its size and biodiversity (El Madani et al 2011). The Lagoon of Nador is among the largest lagoons in Africa, with an area of 115 km^2, 27 km long and 7.5 km wide; it can reach a depth of 8 m (Jeyar et al 2017). Nador Lagoon is located on the southern shore of the Mediterranean Sea on the northeast side of the Moroccan coast (Figure 1).

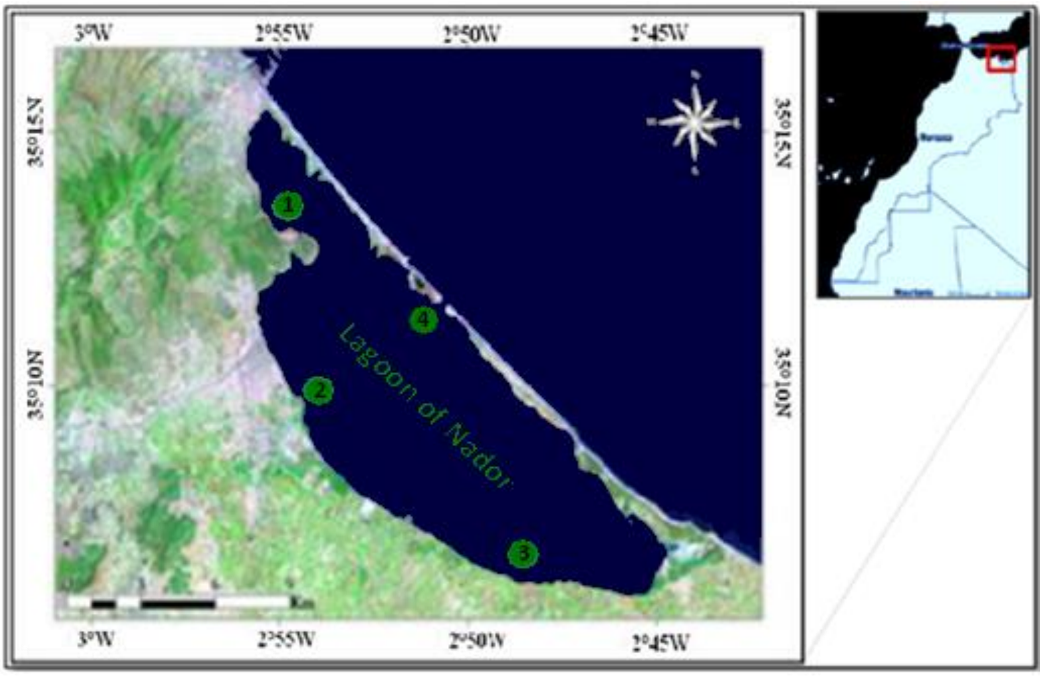


Figure 1. Distribution of sampling stations.

Its geographical coordinates are: 35°10'N latitude and 02°45'-02°57' E-W longitude. The Lagoon of Nador is also one of the most important Mediterranean lagoons by its biodiversity. On a national scale, the Lagoon of Nador is classified among the Sites of Biological and Ecological Interest (SIBE) (Daoudi et al 2013).

During this study we have chosen four sampling stations according to the environmental characteristics of this lagoon (Figure 1): Station 1 - corresponds to Marina (depth 5.7 m); Station 2 - corresponds to Oued Caballo (depth 0.7 m); Station 3 - corresponds to Oued Bou Areg (depth 0.7 m); Station 4 - corresponds to the pass (depth 7.73 m).

Physico-chemical analyses and morphological identification. Measurements of some physico-chemical parameters and phytoplankton sampling were carried out in four stations, during the two seasons, spring and summer, from 2018 to 2019. The physico-chemical analyses of the waters of the Nador Lagoon measured included temperature and salinity (both were performed *in situ* using an ORION STAR A122 multiparameter). Nutrient content (NO_2, NO_3) was evaluated by spectrophotometry (ZuZi, model 4201/50).

Phytoplankton sampling was carried out by filtering using a standard plankton net, characterized by a 24 cm opening and a 20 µm mesh size. Phytoplankton sampling was carried out once a month. At each station, 50 mL of filtered water was collected. The samples were collected from a depth of 0.5 m. The filtration was done with a standard plankton net, characterized by an opening of 24 cm and a mesh of 20 µm. Once collected, a part of samples was fixed immediately with formalin (4%) and another part remained in the living state. The filtered samples were sedimented for 24 hours in sedimentation chambers in the laboratory of INRH (National Institute of Fisheries Research of Nador).

During this present work, the identification and quantification of cell abundance (cell L^{-1}) was performed using an inverted optical microscope (Leica DM750) and the number of cells was estimated using the Utermöhl method (Utermöhl 1958). The identification of diatom species was performed according to Hendey (1964), Round et al (1990), Chrétiennot-Dinet et al (1993), Tomas (1996) and Hasle & Syvertsen (1997).

Statistical analysis. In order to examine the joint distribution of the variables studied, we used descriptive multivariate analyses to better structure and summarize our data. Thus, we used the principal component analysis (PCA). This analysis was carried out using R software. This analysis was used to detect similarities or dissimilarities between the data of *Cocconeis* and *Licmophora* with environmental parameters.

Results and Discussion

Spatio-temporal variation of in-situ determined parameters. The recorded values of temperature during the spring period showed that the maximum value of 21°C was recorded at station 3, while the minimum value of 18.2°C was observed at station 4, with an average of 19.6°C. During the summer period, the surface water temperatures observed temporally were moderate, with an average of 25.45°C, oscillating between a minimum value of 24.2°C recorded at station 3 and a maximum value of 26.7°C at station 1 (Figure 2). The value of the average temperature found is comparable to that found by other authors (Mostareh 2017; Daoudi 2011; Riouchi et al 2021).

In the present study and during the spring period, the average salinity of the Lagoon of Nador was 36.6 ppm and oscillated between 36 and 37.2 ppm, the limits being recorded at stations 4 and 3, respectively. During the summer period, the salinity showed some spatiotemporal variations, but remained characteristic to the marine environment. In general, the values recorded in summer showed a maximum value of 38 ppm at station 3 and a value of 36.2 ppm at station 2, with an average of 37.1 ppm (Figure 3). The value of the average salinity found is comparable to that found by Aknaf et al (2017).

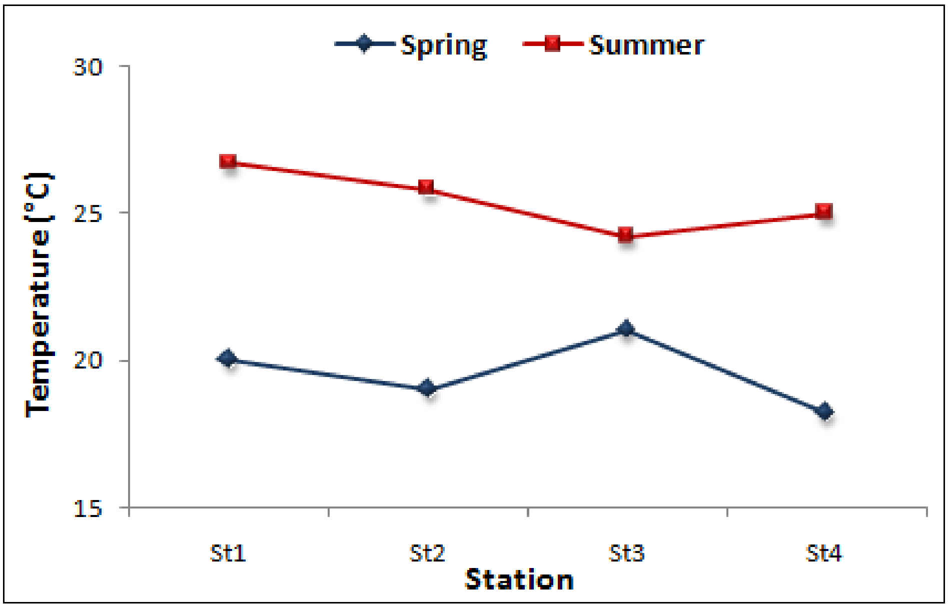


Figure 2. Spatial and temporal variation of temperature recorded during the spring and summer period in the 4 stations of Nador Lagoon.

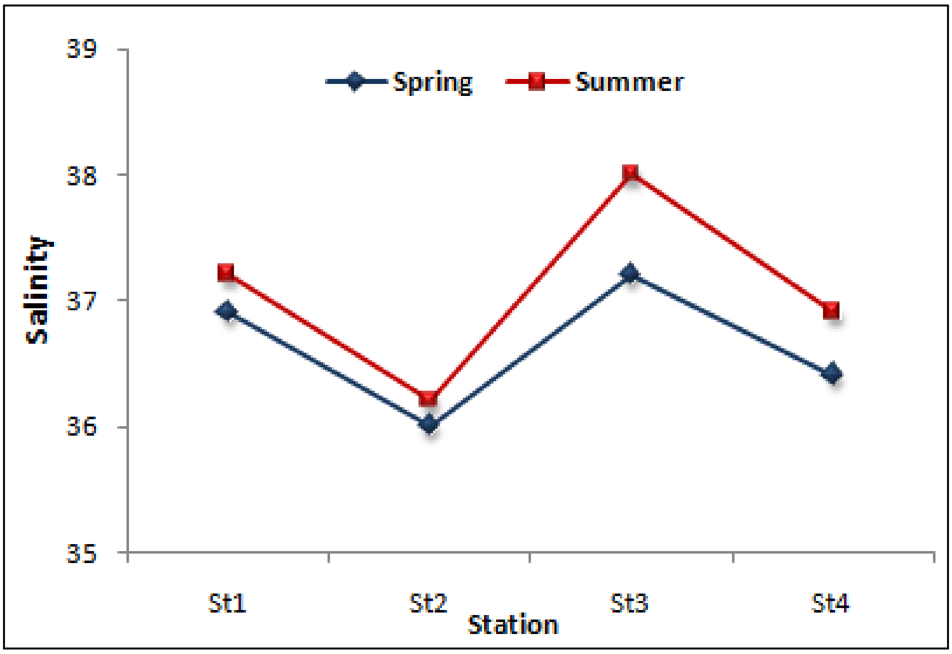


Figure 3. Spatial and temporal variation of salinity recorded during the spring and summer periods.

Spatial-temporal variation in nutrient concentrations. The concentrations of nutrients (nitrates, nitrites), in the Lagoon of Nador during the spring period showed levels varying between 0.185 and 0.835 and 0.007-0.037 mg L^{-1}, respectively. The averages were 0.51 and 0.022 mg L^{-1}, respectively (Figure 4).

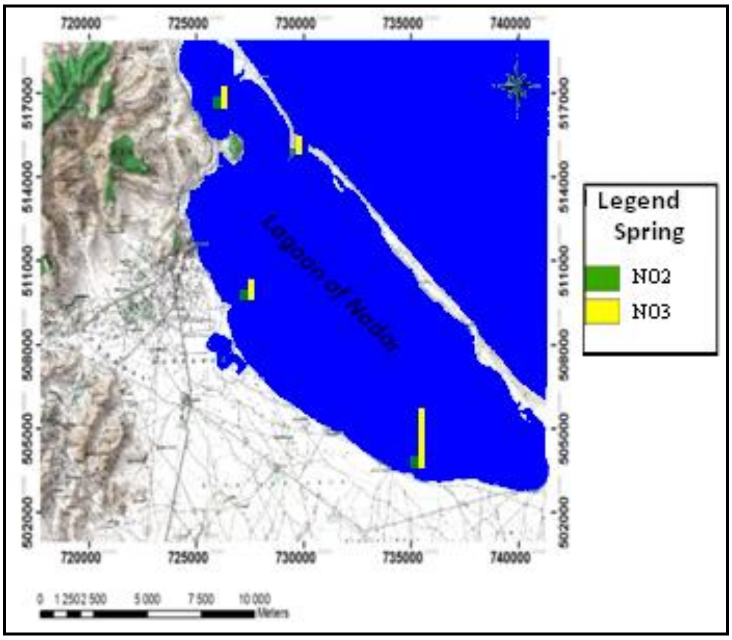


Figure 4. Spatial and temporal variation in nutrient concentrations during the spring period.

The maximum concentration of nitrite (NO_2) during the spring period reached a value of 0.037 mg L^{-1} at station 3 and a minimum value of 0.007 mg L^{-1} at station 4. These concentrations are comparable with that found by Mostareh (2017). The maximum concentration of nitrate (NO_3) during the spring period reached a value of 0.835 mg L^{-1} at station 3, and a minimum value of 0.185 mg L^{-1} at station 4. These concentrations are comparable with those reported by Bloundi (2005) and by Zahra et al (2013), and lower than those found by El Madani (2012) and by Mostareh (2017).

The minimum and maximum concentrations of nutrients (nitrates, nitrites) in the Lagoon of Nador during the summer period showed levels varying between 0.306-0.346 and 0.016-0.075 mg L^{-1}, respectively. The averages were 0.326 and 0.045 mg L^{-1}, respectively. (Figure 5).

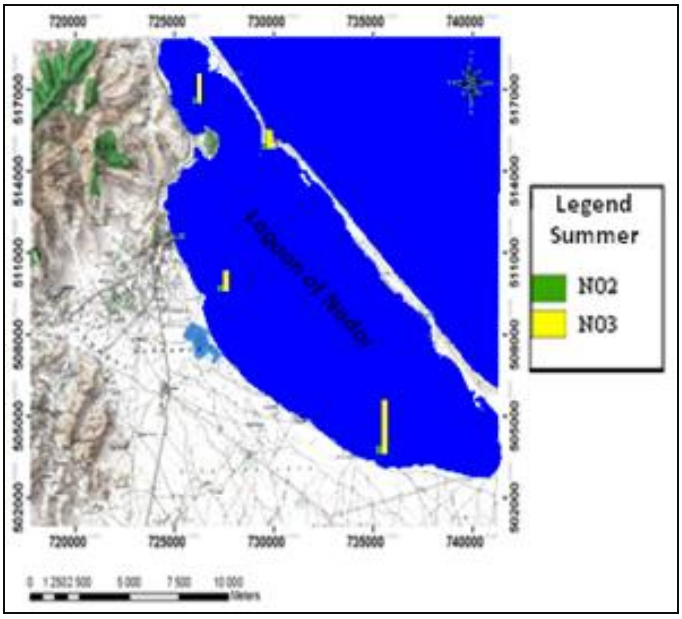


Figure 5. Spatial and temporal variations in nutrient concentrations during the summer period.

The maximum concentration of NO_2 during the summer period reached a value of 0.075 mg L^{-1} at station 3, and a minimum value of 0.016 mg L^{-1} at station 4. These concentrations are comparable with those found by Mostareh (2017). The maximum concentration of NO_3 during the summer period reached a value of 0.346 mg L^{-1} at station 3, and a minimum value of 0.306 mg L^{-1} at station 1. These concentrations are comparable with those found by El Madani (2012) and Mostareh (2017).

Benthic diatoms Licmophora and Cocconeis. In Nador Lagoon, two genera of diatoms were present at the four study stations, *Cocconeis* and *Licmophora*.

The genus *Cocconeis* had the particularity to be represented by 4 species, namely *Cocconeis scutellum* Ehrenberg 1838, *Cocconeis cf. guttata* Hustedt & Aleem 1951, *Cocconeis placentula* Ehrenberg 1838, and *Cocconeis* sp. The genus *Licmophora* had the particularity to be represented by 9 species, namely: *Licmophora abbreviata* C. Agardh, 1831, *Licmophora dalmatica* (Kützing) Grunow, 1867, *Licmophora danicus*, *Licmophora paradoxa* (Lyngbye) C. Agardh 1828, *Licmophora falabellata* (Greville) Agardh,1828, *Licmophora paradoxa* (Lyngbye) C. Agardh,1828, *Licmophora gracilis* (Ehrenberg) Grunow, 1867, *Licmophora remulus* Grunow, 1867, *Licmophora* sp.

The frequency of occurrence by sampling stations, which gives a more precise value of the spatial distribution of the taxa, allowed us to classify the taxa according to the importance of their occurrence. Table 1 clearly shows that *C. scutellum* and *L. gracilis* were the most frequent, being present in all stations.

Table 1

List of benthic diatoms identified in the Lagoon of Nador

Species	*St1*	*St2*	*St3*	*St4*	*Frequency*
Cocconeis scutellum Ehrenberg 1838	+	+	+	+	4
Cocconeis cf. guttata Hustedt & Aleem 1951	-	-	+	-	1
Cocconeis placentula Ehrenberg 1838	-	+	+	-	2
Cocconeis sp.	+	+	+	-	3
Licmophora abbreviata C. Agardh, 1831	+	+	-	+	3
Licmophora dalmatica (Kützing) Grunow, 1867	+	+	-	+	3
Licmophora danicus	-	+	-	-	1
Licmophora paradoxa (Lyngbye) C.Agardh 1828	-	+	-	-	1
Licmophora falabellata (Greville) Agardh,1828	+	+	-	-	2
Licmophora paradoxa (lyngbye) C. Agardh,1828	+	+	+	-	3
Licmophora gracilis (Ehrenberg) Grunow, 1867	+	+	+	+	4
Licmophora remulus Grunow, 1867	+	+	-	+	3
Licmophora sp.	+	+	+	-	3

Diatoms (Bacillariophyceae) belong to the phylum Chromophytes. Their classifications are numerous and have been subject to successive revisions (Hustedt 1930; Lange-Bertalot & Krammer 1987). The monoraphid genus *Cocconeis* belongs to the order Achnantales and Coccoeidaceae family. The genus has some of the most architecturally complex species of diatoms due to their heterovalvarity, developed and functional girdle bands and complex valves (Kobayasi & Nagumo 1985; Round et al 1990; De Stefano & De Stefano 2005; De Stefano & Romero 2005). Most studies on *Cocconeis* have focused on epilithic (De Seve & Goldstein 1981; Poulin et al 1984) or epiphytic species (Siqueiros-Beltrones et al 1985; Sullivan 1979; Jacobs & Noten 1980), while others have stressed the importance of these diatoms as early colonizers of hard substrates (Sieburth & Thomas 1973; Hudon & Bourget 1981; Ferreira & Seeliger 1985).

At the level of this present work, the total cell density of *Cocconeis* in the waters of the Lagoon of Nador in spring, oscillated between a minimum of 480 cells L^{-1}, observed at station 4, and a maximum of 5840 cells L^{-1} at station 2 (Figure 6). However, in the summer period, the minimum total cell density of *Cocconeis* recorded at the four stations sampled in the Lagoon of Nador oscillated between a minimum of 120 cells L^{-1}, observed at station 4, and a maximum of 3000 cells L^{-1} at station 2 (Figure 6). The cell density found during this work is higher than that found by Mostareh (2017).

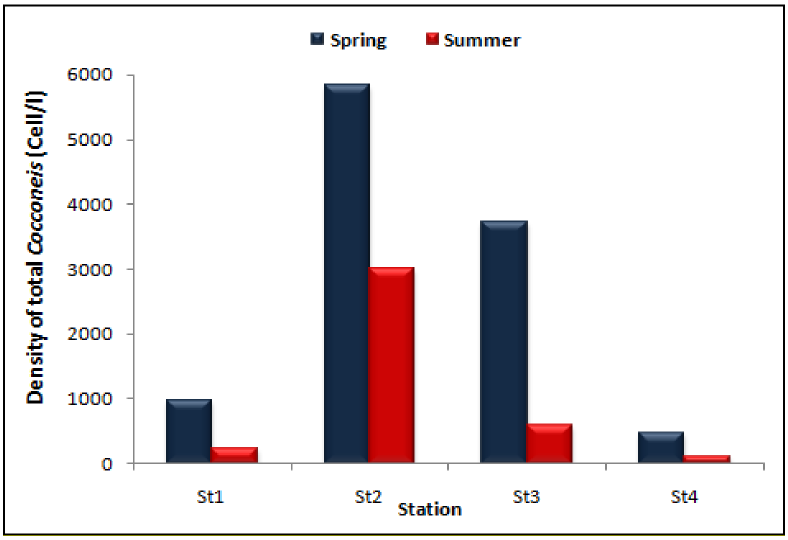


Figure 6. Density of total *Cocconeis* during the spring and summer periods.

The genus *Licmophora* belongs to the class of Bacillariophyceae (corresponding to the old term "diatoms") of the phylum Ochrophyta, order Licmophorales and family Licmophoraceae (Comère 1901).

During the spring period, the maximum total cell density of *Licmophora* in the Lagoon of Nador reached a density of 520 cells L^{-1} in station 2, and a minimum density of 80 cells L^{-1}, at station 4 (Figure 7). However, during the summer period, the minimum and maximum total cell density of *Licmophora* recorded at the four stations were 100 cells L^{-1} at station 1, and 840 cells L^{-1} at station 2. The cell densities found during this work are comparable to those found by El Madani (2012), but are lower than those found at King George Island, Antarctica, described by Kang et al (2002).

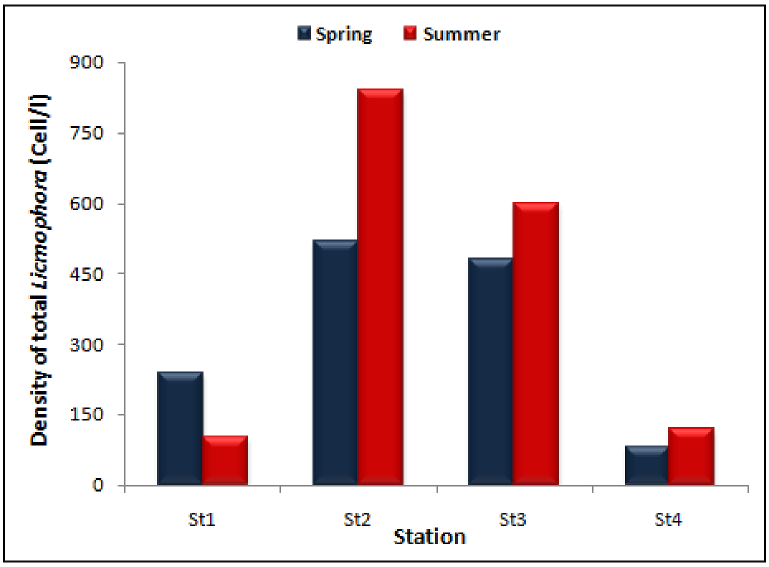


Figure 7. Density of total *Licmophora* during the spring and summer periods.

Relationship between environmental factors and density of Licmophora and Cocconeis. The multivariate analysis (PCA) showed that during the spring period, the F1 axis alone explains 64.65% of the total variation (Figures 8 and 9). According to the F1 axis, there is a positive correlation between the environmental parameters (temperature, salinity, NO_2 and NO_3) and the two taxa (*Licmophora* and *Cocconeis*). According to the F2 axis, there is a positive correlation of the variables NO_2, NO_3, and total number of *Cocconeis* and *Licmophora*, and a negative correlation between temperature and salinity.

In general, there is a clear positive correlation between the two taxa (*Cocconeis* and *Licmophora*) with the nutrients (NO_2 and NO_3) and a negative correlation with the two parameters (temperature and salinity). We can see that the taxon *Cocconeis* correlated with NO_2 and the taxon *Licmophora* correlated with NO_3.

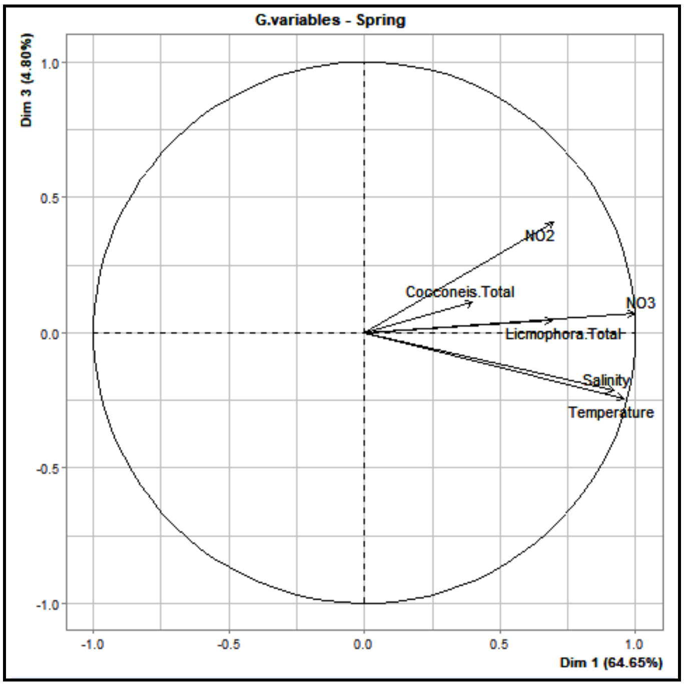


Figure 8. Principal component analysis (PCA) of *Licmophora* and *Cocconeis* density in relation to environmental factors (temperature, Salinity, NO_2, NO_3) during spring.

	Temperature	Salinity	NO2	NO3	Cocconeis.Total	Licmophora.Total
Temperature	1	-0.62		-0.22	0.15	-0.29
Salinity	-0.62	1	0.63	0.49	-0.63	-0.15
NO2		0.63	1	0.85	-0.18	[illegible]
NO3	-0.22	0.49	0.85	1	0.26	0.61
Cocconeis.Total	0.15	-0.63	-0.18	0.26	1	0.86
Licmophora.Total	-0.29	-0.15	[illegible]	0.61	0.86	1

Figure 9. Table of correlation between variables and factors during spring.

Figures 10 and 11 represent the PCA of *Licmophora* and *Cocconeis* density in relation to environmental factors (temperature, salinity, NO_2, NO_3) during the summer period. The F1 axis explains 42.97% of the total variation, and the F2 axis explains 37.53%. According to the F1 axis, there is positive correlation between some of the environmental parameters (salinity, NO_2 and NO_3) and *Licmophora*, and a negative correlation between *Cocconeis* and the salinity parameter. Generally, it is clearly seen that *Cocconeis* correlated positively with temperature and negatively with salinity. *Licmophora* correlated positively with NO_3, and negatively with salinity.

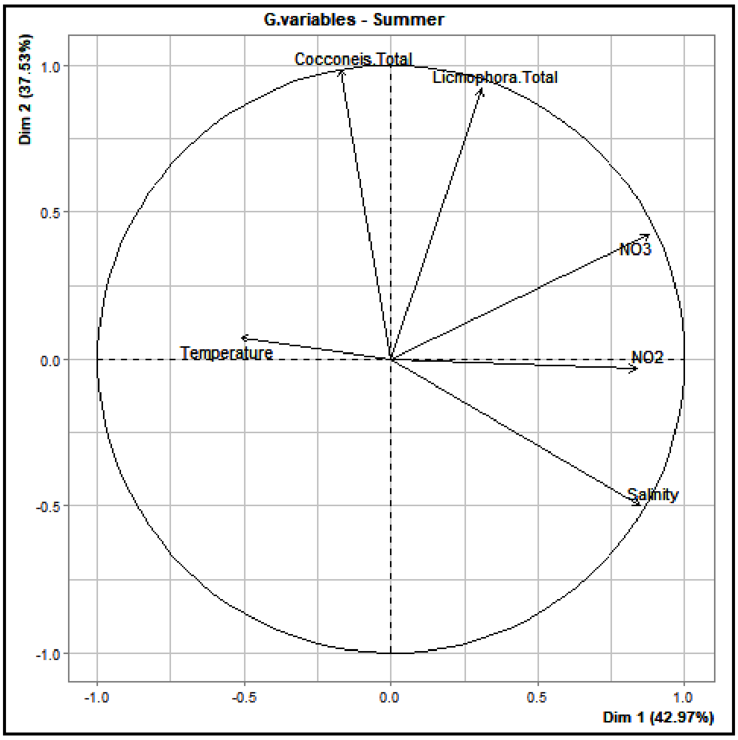
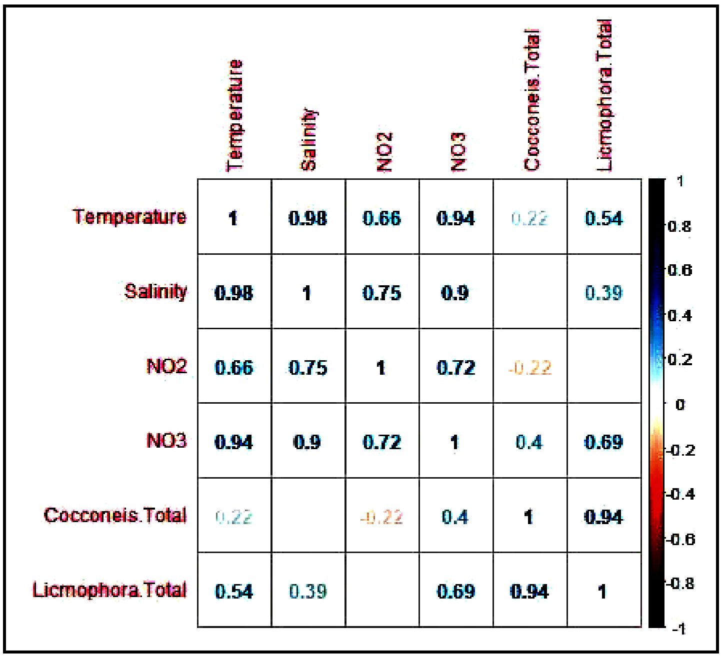


Figure 10. Principal component analysis (PCA) of *Licmophora* and *Cocconeis* density in relation to environmental factors (temperature, salinity, NO_2, NO_3) during summer.



	Temperature	Salinity	NO2	NO3	Cocconeis.Total	Licmophora.Total
Temperature	1	0.98	0.66	0.94	0.22	0.54
Salinity	0.98	1	0.75	0.9		0.39
NO2	0.66	0.75	1	0.72	-0.22	
NO3	0.94	0.9	0.72	1	0.4	0.69
Cocconeis.Total	0.22		-0.22	0.4	1	0.94
Licmophora.Total	0.54	0.39		0.69	0.94	1

Figure 11. Table of correlation between variables and factors during the summer period.

Conclusions. During this present study, it is clearly noticed that the maximum cell density of *Licmophora* and *Cocconeis* was in stations 2 and 3, characterized by a low depth (0.7 m), and an important concentration of nitrates and nitrites, favoring the development of taxa in these stations. Thus, this subordination is under the continental influence. The minimum cell densities of *Licmophora* and *Cocconeis* were observed at station 4, which corresponds to the new pass, located in the North of the Lagoon of Nador, with a superior depth of 7.73 m, being under marine influence.

Conflict of Interest. The authors declare no conflict of interest.

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